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Saco Bay, Maine: Sediment Budget for Late Twentieth Century to Present

by Andrew Morang

PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes a sediment budget that was developed to support a Regional Sediment Management (RSM) strategy for Saco Bay, ME. The region includes the three Federal navigation projects of Saco River, Wood Island Harbor/Biddeford Pool, and Scarborough River. This sediment budget will help address sediment management issues in conjunction with the needs of eroding beaches in the communities of Saco, Biddeford, and Scarborough. Figure 1 shows the study area and the sediment budget cells.

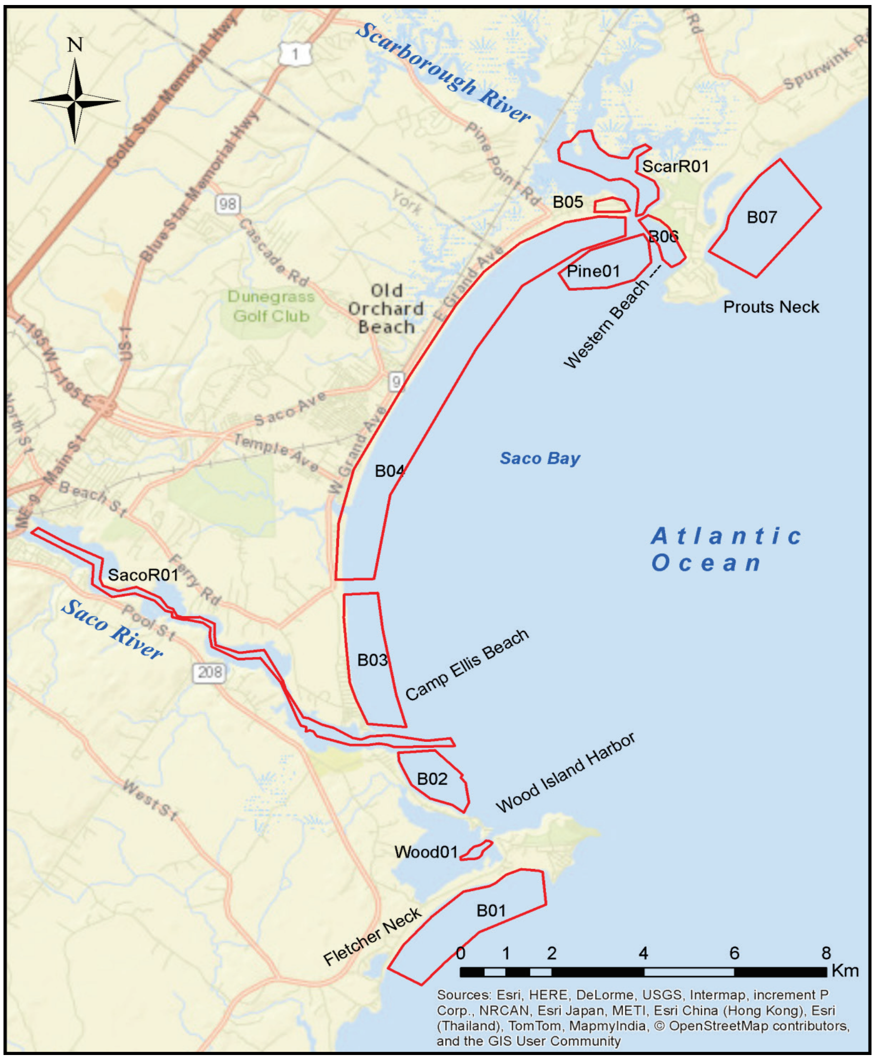

Figure 1. Saco Bay, ME, study area and sediment budget cells.

BACKGROUND: The construction history, previous studies of the Saco River navigation project, and proposed alternatives to mitigate erosion at Camp Ellis are described in the Section 111 Main Report of the U.S. Army Corps of Engineers (USACE), New England District (NAE) (USACE, NAE 2013), and the Coastal Engineering Appendix of New England District (USACE NAE 2012). Both documents contain references to other studies and technical papers. Woods Hole Group (2013a) calculated shoreline change statistics for the Saco Bay area. For this sediment budget, the statistics from the end point method for the 1944–2010 period were used to compute overall advance or retreat for each beach cell. Figure 2 shows the locations of transects used to compute shoreline changes. Transects were at 50-feet (ft) intervals. Dredging statistics were provided by the USACE North Atlantic Division, NAD. Sediment volumes were entered into the Sediment Budget Analysis System (SBAS) software (Rosati and Kraus 2001; Dopsovic et al. 2002) and are available for future modification. SBAS was developed under the USACE Navigation Research, Development and Technology Program. Values for individual cells are reproduced in Appendix A. U.S. customary units have been used in this technical note as per original data collection and reporting of dredging volumes.

Figure 2. Transects used to compute shoreline changes (from Woods Hole Group 2013a).

SEDIMENT BUDGET CELL DESCRIPTIONS:

Sediment Budget Cell B01. No data are available for this cell. Because of the location of Cell B01 south of Fletcher Neck and the adjacent rocky headland, this cell is isolated from sediment processes in Saco Bay (Figure 3). This cell was not considered in the sediment budget.

Figure 3. Sediment budget cells in southern section of Saco Bay study area. (Aerial photography from ESRI® Maps and Data.)

Sediment Budget Cell Wood01. Wood Island Harbor and entrance channel (Figure 3) have only been dredged four times in over a century, based on data from USACE NAE (Table 1). The initial improvement of the 6 ft anchorage was constructed in 1956 and has only needed maintenance dredging once, in 1989. Therefore, dividing 38,452 cubic yards (yd^3) by 33 years (yr) yields an assumed (average) shoaling rate of 1,170 yd^3/yr. The Saco River is the source of sand entering the harbor (Kelley et al. 2005).

Sediment Budget Cell B02. This is the short beach south of the Saco River south jetty (Figures 3 and 4). For Cell B02, covering Transects 6–94 of Woods Hole Group (2013a; see Figure 2 for locations), beach advance was 0.442 ft/yr, yielding DeltaV (ΔV) = 2,600 yd^3/yr. The source of this sand is the Saco River.

Table 1. Wood Island Harbor and Biddeford Pool Dredging		
Date	**yd³**	**Notes**
1992	17,300	10 ft entrance channel through Wood Island Harbor.
1989	38,452	Maintenance dredging of the 6 ft Pool anchorage basin.
1956	74,781	Improvement dredging of the 6 ft Pool anchorage–new project.
1871	4,000	Improvement for 5 ft MLW channel at Biddeford.
Basin only 1989	38,452	
Years 1956–1989	33	
Annual average	1,170	

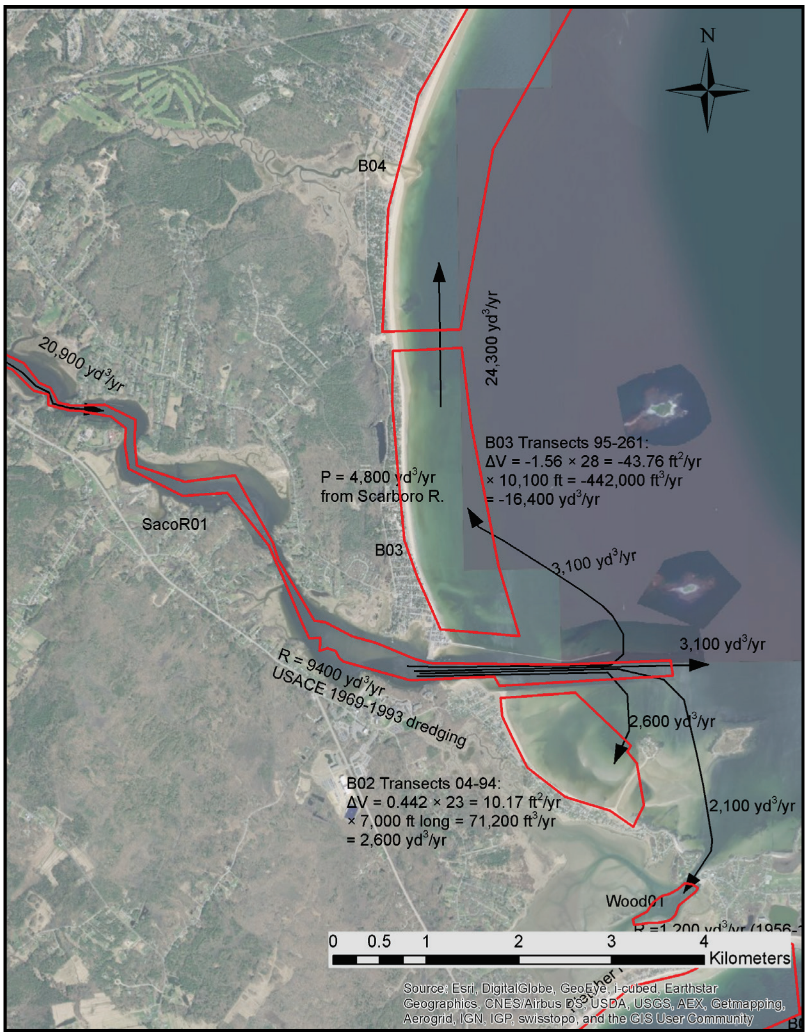

Figure 4. Central zone of Saco Bay study area.

Sediment Budget Cell SacoR01. Cell SacoR01 includes the Saco River below the town of Biddeford and extending to the jetties at the coast (Figure 4). Normandeau Associates (1994) estimated that between 13,000 yd^3/yr and 20,900 yd^3/yr of sand is transported down the Saco River. For this budget, the larger value is used because it adequately balances dredge removal and flux to the adjacent beaches. Based on USACE NAE dredging data for the period 1969–

1993, the average annual dredging is 9,400 yd^3 (Table 2). These dates cover the era when the contemporary 8 ft channel and 6 ft anchorage were in existence. This value is slightly less than the 11,700 yd^3 in the Normandeau Associates (1994) report. Kelley et al. (2005) estimated that 3,100 yd^3 moved north to the beach off Camp Ellis (Cell B03), 3,100 yd^3 moved offshore, and 2,100 yd^3 moved south to Wood Island Harbor (Figure 4).

Table 2. Saco River Dredging

Date	yd^3	Notes
1993	19,378	Complete maintenance of 8 ft channel and three lower 6 ft anchorage areas. Placed offshore north of Wood Island.
1992	26,464	Maintenance of 8 ft channel and 6 ft anchorage areas (contract terminated). Placed offshore north of Wood Island.
1992	15,785	Upper 8 ft channel dredged by *Currituck* with in-river disposal.
1982	7,300	
1978	69,300	Maintenance of 8 ft channel and 6 ft anchorage areas.
1969	87,354	Maintenance of 8 ft channel.
1969	73,130	Improvement of two 6 ft lower harbor anchorage areas.
1939	65,861	8 ft bar channel.
1938	92,464	
1935	88,429	
1927	56,000	Improvement by dredging 8 ft channel.
1916	2,000	Maintenance of 7 ft channel.
1912	1,840	
1911	27,729	Improvement of 7 ft channel.
1894	44,175	Improvement of 6 ft channel.
1887	19,408	Improvement dredging for 6 ft channel.
Sum 1969–1993:	225,581	
Years	24	
Annual average	9,400	

Source: Saco River, Saco and Biddeford, Maine; Project Construction and Maintenance History, from Mark Habel, NAE.

All sediment entering the cell has a riverine source. FitzGerald et al. (1993) collected over 200 sediment samples from the Factory Island Dam out to 1 kilometer (km) (0.6 miles) offshore of the jetties in 1992 and 1993. The estuary is floored with medium to coarse sand, with finer-grain sediment in the wide tidal flat portions. Seaward of the jetties, the sediment is uniformly fine sand. After the large 1993 freshet, a majority of the sediments were coarser, more poorly sorted, and contained a greater percentage of feldspar and rock fragments, indicating an upriver source (Manthrop 1995). Polishing and pitting of turbine blades at the dam during periods of high discharge corroborates the riverine sourcing (FitzGerald et al. 1993). Spring freshets completely supplant tidal flow in the Saco River and are an important factor in supplying coarse sediment to the estuary mouth (FitzGerald 1996).

Before the mid-1800s, a large ebb shoal with shallow bars at the mouth of the Saco River made navigation hazardous. After jetty construction, tidal currents were funneled along the channel, and tidal flow across the shoal ceased (Kelley et al. 2005). The shallow platform north and south

of the jetties was subject to shoaling waves, resulting in onshore movement of sand bars in the 1870s (Farrell 1972). In effect, the former shoal collapsed, but by 1909, following a few decades of beach accretion, the beaches north of the jetty began to suffer retreat. In this contemporary sediment budget, there is no cell representing an ebb shoal. Sand flushing out of the Saco jetties is shown as moving directly to beaches north or south and to the offshore, although in reality there may be temporary residence on the seabed.

Cell SacoR01 is unbalanced, with a residual 600 yd^3/yr. The residual is caused by uncertainty in the amount of the material coming down the Saco River and uncertainty in the volumes moving out past the jetties. Sediment coming down the Saco will vary year to year, depending on rainfall events, severity of the winter, and storage behind dams.

Sediment Budget Cell B03. Cell B03, adjacent to Camp Ellis, is north of the Saco River north jetty and extends to near the junction of Bayview Road with Seaside Avenue (Figure 4). The cell is 10,100 ft long and includes Transects 95–260 of the Woods Hole Group (2013a) analysis. This beach has suffered chronic erosion for decades because sediment was transported northward but did not have a significant source of sediment coming into the area (Woods Hole Group 2013b). Based on the average retreat of 1.56 ft/yr, ΔV = -16,400 yd^3/yr, using a closure depth of -28 ft. This is the same depth value used in the Saco River and Camp Ellis Engineering Appendix B (p. 100) for computation of beach nourishment spreading (USACE, NAE 2012). By adding the ΔV caused by beach erosion to placement (4,800 yd^3/yr) and Saco River input ($Q_{source1}$ = 3,100 yd^3/yr), longshore sand transport to the north to Cell B04 is 24,300 yd^3/yr (see Appendix A for details).

In the past, sand loss from the Camp Ellis area was significantly greater. Kelley and Anderson (2000), citing the appendices of the USACE (1955) beach erosion study, stated that the annual loss of sand between 1859 and 1955 was 81,000 yd^3. This covered the era of severe beach retreat in the late 1800s and early 1900s, before revetments and other structures were installed to armor the beach. For this study, the more recent statistics are used covering the 1944–2010 period when shoreline retreat was less. Based on these retreat values, northward transport is now computed to be 24,300 yd^3/yr. Figure 12 of Kelley et al. (2005) presents a value of 22,200 yd^3/yr for northward transport in this area.

Sediment Budget Cell B04. Cell B04 extends from Bayview Road north to the Scarborough River jetty (Figures 4 and 5). The cell is 73,800 ft long and includes Woods Hole Group (2013a) transects 261–804. The boundary of Cells B03 and B04 is the transition where shoreline change shifts from retreat to advance, based on the 1944–2010 end point analysis. With an average advance of 1.46 ft/yr, ΔV = 57,000 yd^3/yr in B04. Shoreline change rate varies in the cell and increases near the Scarborough River, north of approximately transect 680. In the center of the Bay, Woods Hole Group (2013b) determined that sediment flux was variable, depending on bathymetry and input wave conditions. Despite these variations in conditions, there is no obvious morphologic or structural feature (such as a jetty) to indicate that the cell should be divided into two or more smaller cells.

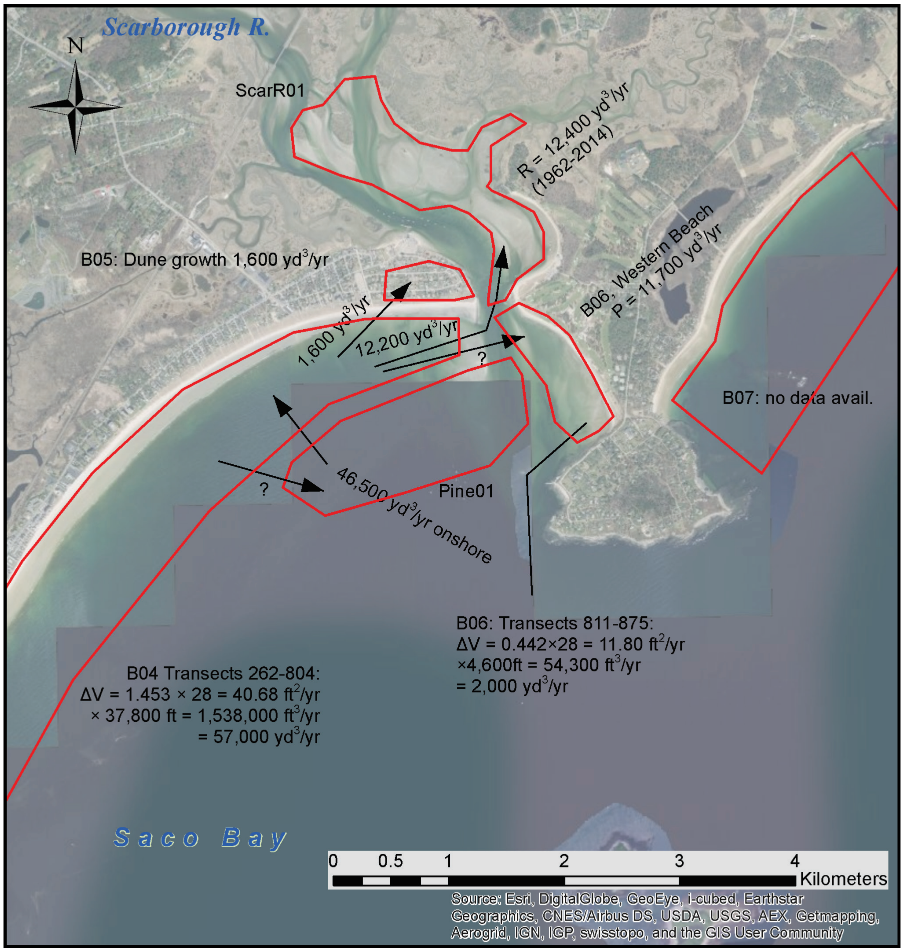

Figure 5. North section of the study area, including the Scarborough River.

Approximately 12,200 yd^3/yr of sand leaves Cell B04 and enters the Scarborough River. This value equals the annual Scarborough dredging volume, on the assumption that all sand entering the mouth of the Scarborough has an open coast source. Some sand may bypass the mouth of the Scarborough and move into B06, Western Beach, due to the complicated tidal circulation in the region. The amount is unknown and shown as a “?” at the flux arrow in Figure 5. Determining the exact circulation would be very difficult, especially as the volumes likely change year to year, depending on wave climate.

Some sand may also move offshore to Cell Pine01. To balance the fluxes in Cell B04, it is necessary to include onshore transport of 46,500 yd^3/yr. The offshore shoal area (Cell Pine01) grew significantly in the late 1800s and early twentieth century (discussed below). Kelley et al. (2005) also invoked an offshore source, and Farrell (1972) documented onshore-offshore transport.

Sediment Budget Cell Pine01. This area of undefined dimensions is located off the mouth of the Scarborough River and south of Western Beach (Figure 5). Kelley et al. (2005) calculated that from 1859–1955, approximately 4.5 million yd^3 of sand accumulated offshore of Pine Point, causing seabed shoaling of 1.5–3 ft. The source of this sand was (a) loss from the Camp Ellis area

following Saco River jetty construction in the mid-1800s (i.e., reworking of sand from the Saco ebb-tide delta and the shoreface) and (b) dredge material from the Scarborough River that was disposed offshore. Onshore transport contributes to the beach accumulation in B04 (Kelley et al. 2005). The volume of 47,000 yd^3/yr is based on the need to balance the fluxes in and out of B04.

Sediment Budget Cell B05. Cell B05 represents the accumulation of sand on the beach at Pine Point (Figure 5). Kelley et al (2005) computed dune accumulation from 1859–1991 ranged from 1,100–2,210 yd^3/yr. An average value of 1,600 yd^3/yr has been used in this budget.

Sediment Budget Cell B06 (Western Beach). Over the period 1864–2003, Western Beach was relatively stable, with periods of accretion and erosion (Woods Hole Group 2004). Based on shoreline change for Transects 811–875, the average advance between 1944 and 2010 was 0.42 ft/yr, yielding ΔV = 2,000 yd^3/yr. A single nourishment has been recorded: in November–December 2004, hydraulic pipeline maintenance dredging of the 6 ft channel and 6 ft anchorage in the Scarborough River placed 82,000 yd^3 on Western Beach. Assuming a future cycle of 10 yr for placements, P = 8,200 yd^3/yr. The cell is unbalanced, with residual of 6,200 yd^3/yr.

Sediment Budget Cell Scar01. The Scarborough River has an average removal of 12,200 yd^3/yr based on 1962–2015 dredging (113,200 yd^3 was scheduled to be removed in 2014 but was postponed because of equipment failure. The work is scheduled to be completed in 2015; Table 3). The calculation of average dredging volume did not include the initial construction volume. There is no inland source of sand, so sand accumulating in the entrance area is assumed to come from the open bay, carried by tidal currents.

Table 3. Scarborough River Dredging

Date	yd^3	Notes
2015	113,200	Specified for 2014 but postponed. Assume work to be completed in 2015.
2005	82,047	Placed at Western Beach, Prouts Neck.
1997	95,000	Placed off Camp Ellis Beach.
1975	9,090	Sidecast.
1974	188,800	
1970	47,000	
1966	32,577	Open water.
1963	70,000	
1962	80,000	
1956	128,099	New work, begun Sep 1956.
Sum 1962–2015	717,714	
Years	59	
Annual average	12,200	

Source: Scarborough River (Pine Point Harbor), Scarborough, Maine; Project Construction and Maintenance History from Mark Habel, NAE.

Sediment Budget Cell B07. Cell B07 is on the east side of Prouts Neck and includes the Scarborough Beach State Park. No data are available on shoreline changes or beach nourishment. Because of its location, it has minimal interaction with the Saco Bay littoral system.

SUMMARY: This sediment budget covers the recent era, approximately from the 1940s to the present. Longshore sediment transport along most of Saco Bay is from south to north, as shown by sediment accumulation at the Scarborough River jetty and modeled by Woods Hole Group (2013b). The source of most of the sand in the system is the Saco River and the continuing adjustment of the Saco ebb shoal (Kelley et al. 2005). Shoreline change statistics computed by Woods Hole Group (2013a) verify the continuing erosion of the beach in the Camp Ellis area. The statistics also indicate that Western Beach has undergone episodes of retreat and advance but overall has been relatively stable, and it was nourished in 2005 with 82,000 yd^3 of sand from the Scarborough River. Cell B04, extending from Bayview Road north to the Scarborough River jetty, had experienced overall volume increase from 1944–2010 with ΔV (beach advance) of 57,000 yd^3/yr. To account for this increase in volume, onshore sediment transport is necessary.

RECOMMENDATIONS: One of the crucial pieces of information used in this study was the shoreline change statistics computed by Woods Hole Group (2013a). This allows computation of ΔV, the volume of sand gained or lost from beaches. Future sediment budget studies at this or other sites should also have a comprehensive shoreline mapping analysis. In addition, dredge statistics are crucial and need to be coupled with disposal location and volume.

To further refine this sediment budget, a better evaluation of the volume of sediment coming down the Saco River is needed. This could be partially accomplished by dredging a sediment trap and monitoring the infilling rate, coupled with a sediment and current study similar to the one described by FitzGerald et al. (1993) and Manthrop (1995).

ADDITIONAL INFORMATION: This Coastal and Hydraulics Engineering Technical Note (CHETN) was prepared as part of the USACE Regional Sediment Management (RSM) Program by Dr. Andrew Morang, U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Vicksburg, MS. John Winkelman and Mark Habel (both with U.S. Army Engineer District, New England) provided field data and analysis support. Questions pertaining to this CHETN may be directed to Andrew Morang (*Andrew.Morang@usace.army.mil*), John Winkelman (*John.H.Winkelman@usace.army.mil*), Mark Habel (*Mark.L.Habel@usace.army.mil*), or to the USACE RSM Program Manager, Linda Lillycrop (*Linda.S.Lillycrop@usace.army.mil*). Additional information regarding the RSM Program may be obtained from the RSM web site *http://rsm.usace.army.mil*.

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REFERENCES

Dopsovic, R., L. Hardegree, and J. D. Rosati. 2002 (rev. 2003). *Sediment Budget Analysis System-A: SBAS-A for ArcView© application.* ERDC/CHL CHETN-XIV-7. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-xiv-7.pdf*

Farrell, S. C. 1972. Present coastal processes, recorded changes, and the post-Pleistocene geologic record of Saco Bay, Maine. Ph.D. dissertation, University of Massachusetts.

Fitzgerald, D. M., P. A. Manthorp, C. Kuo, S. van Heteren, L. K. Fink, Jr., and J. T. Kelley. 1993. Estuarine circulation and sediment transport trends in the lower Saco River. In *Geological Society of America, Abstracts with Programs; (United States)* 25:2.

FitzGerald, D. M. 1996. Geomorphic variability and morphologic and sedimentologic controls on tidal inlets. Special Issue No. 23; Understanding physical processes at tidal inlets. *Journal of Coastal Research*. (Based on contributions by Panel on Scoping Field and Laboratory Investigations, *Coastal Inlet Research*. Winter 1996, 47–71.)

Kelley, J. T., and W. Anderson. 2000. The Maine shore and the Army Corps: A tale of two harbors, Wells and Saco, Maine. *Marine Policy Review* 9(2):20–34.

Kelley, J. T., D. C. Barber, D. F. Belknap, D. M. FitzGerald, S. van Heteren, and S. M. Dickson. 2005. Sand budgets at geological, historical, and contemporary time scales for a developed beach system, Saco Bay, Maine, USA. *Marine Geology* 214:117–142.

Manthorp, P. A. 1995. Estuarine circulation and sediment transport in the Saco River Estuary, ME. MA thesis, Boston University, Department of Geology.

Normandeau Associates. 1994. *A dredged material management study for coastal Maine and New Hampshire*. Falmouth, MA. Prepared for U.S. Army Corps of Engineers, New England Division, Waltham, MA.

Rosati, J., and N. Kraus. 2001 (rev. 2003). *Sediment Budget Analysis System (SBAS): Upgrade for regional applications.* ERDC/CHL CHETN-XIV-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-xiv-3.pdf*

Woods Hole Group and Aubrey Consulting. 2004. *Analysis of shoreline change for Western Beach, Saco Bay, Maine*. Falmouth, MA: Report prepared for U.S. Army Corps of Engineers, New England District, Concord, MA.

Woods Hole Group. 2013a. *Saco Bay, ME: Shoreline mapping and sediment transport potential update; Part I.* Falmouth, MA: Prepared for U.S. Army Corps of Engineers, New England District, Concord, MA.

Woods Hole Group. 2013b. *Saco Bay, ME: Shoreline mapping and sediment transport potential update; Part II.* Falmouth, MA: Prepared for U.S. Army Corps of Engineers, New England District, Concord, MA.

U.S. Army Corps of Engineers (USACE). 1955. *Beach erosion control report on cooperative study of Saco, Maine*. Waltham, MA: U.S. Army Corps of Engineers, New England Division.

USACE, New England District (NAE). 2012. *Coastal engineering: Appendix B; Saco River and Camp Ellis Beach, Saco, Maine.* Concord, MA: U.S. Army Corps of Engineers, New England District.

USACE, NAE. 2013. *Saco River and Camp Ellis Beach, Saco, Maine; Section 111 Shore damage mitigation project draft decision document and environmental assessment including finding of no significant impact, and section 404(b)(1) evaluation*. Concord, MA: U.S. Army Corps of Engineers, New England District.

APPENDIX A: SEDIMENT BUDGET CELL DETAILS, SACO BAY, MAINE

V3. Last update: 11 September 2014

Units are yd^3/year. *Source1* = bluffs, river influx, wind. *Sink1* = wind-blown loss or other. *Source2* or *Sink2* = offshore. *Source3* or *Sink3* = other (inlet, channel, trap). *LST1* = right (NE) side of cell viewed from offshore. *LST2* = left (SW) side of cell viewed from offshore. *DeltaV* = beach advance or erosion. *Placement (P)* = artificial (beachfill) disposal. *Removal (R)* = dredging. Yellow = beach cells. Blue = river or harbor cells. (Note: In Table A1, Saco River Cell SacoR01 is shown complete; other cells only show rows which contain data.)

Table A1. Sediment budget cell details, Saco Bay, Maine

Variable	Volume (yd^3/year)	Notes, source
Cell Beach01 (B01), south of Biddeford Pool		
Q_{Source}		No data available.
Q_{Sink}		No data available.
Residual	0	
Cell Wood01, Wood Island Harbor		
$Q_{Source3}$	2,100	From Saco R. (Kelley et al. 2005).
Removal	1,200	USACE 1956–1989.
Residual	900	
Cell Beach02 (B02), south of Saco south jetty, 7,000 ft long		
$Q_{Source-LST2}$	2,600	From Saco R (value based on balancing ΔV).
DeltaV	2,600	Based on 0.442 ft/year x 23 ft closure (23 rather than 28).
Residual	0	
Cell SacoR01, Saco River		
$Q_{Source1}$	20,900	Saco R (from Normandeau Associates 1994)–this value varies annually.
Q_{Sink1}	3,100	To beach to north (Kelley et al. 2005).
$Q_{Source2}$		
Q_{Sink2}	3,100	To offshore shoal (Kelley et al. 2005).
$Q_{Source3}$		
Q_{Sink3}	2,100	To Wood Is. Harbor (Kelley et al. 2005).
$Q_{Source-LST1}$		
$Q_{Sink-LST1}$		
$Q_{Source-LST2}$		
$Q_{Sink-LST2}$	2,600	To beach B02.
Removal	9,400	USACE data 1969–1993 average.
Residual	600	
Cell Beach03 (B03), transects 95–260, north of Saco river north jetty, 10,100 ft long		
$Q_{Source1}$	3,100	From Saco R. (Kelley et al. 2005).
$Q_{Sink-LST1}$	24,300	To B04.
Placement	4,800	USACE data from Scarborough R.
DeltaV	-16,400	Based on -1.56 ft/year × 28 ft closure.
Residual	0	

Cell Beach04 (B04), transects 261–804, 37,800 ft long		
Q_{Sink1}	1,600	Dune growth in B05 (Kelly et al. 2005).
$Q_{Source2}$	46,500	Onshore transport.
$Q_{Sink-LST1}$	12,200	Into Scarborough R. (= to dredge volume).
$Q_{Source-LST2}$	24,300	From B03, mostly from beach erosion there.
DeltaV	57,000	Based on 1.463 ft/year × 28 ft closure.
Residual	0	
Cell Pine01, offshore of Pine Point		
Q_{Sink2}	46500	Onshore transport
Residual	-46500	
Cell Beach05 (B05), Pine Point		
$Q_{Source1}$	1,600	Wind transport (from Kelley et al. 2005).
DeltaV	1,600	Dune accumulation 1859–1991 (from Kelley et al. 2005).
Residual	0	
Cell Beach06 (B06), Western Beach, Prouts Point, 4,800 ft long		
Placement	8,200	Based on 82,047 placement in 2004 ÷ 10 yr (assumption).
DeltaV	2,000	Based on 0.422 ft/year × 28 ft closure.
Residual	6,200	
Cell ScarR01, Scarborough River		
$Q_{Source1}$	0	Assume no sand input from creeks.
$Q_{Source2}$	12,200	From open beach B04.
Removal	12,200	USACE data, 1962–2015 (work schduled for 2014 postponed–assume completion 2015).
Residual	0	
Cell Beach07 (B07), Scarborough Beach State Park		
Q_{Source}		No data available.
Q_{Sink}		No data available.
Residual	0	